Fish composition and distribution in an Alaskan arctic lagoon

by

P.C. Craig[1]

W.B. Griffiths[2]

L. Haldorson[3]

H. McElderry[4]

LGL Ecological Research Associates

Suite 201. 505 West Northern Light Blvd.

Anchorage, Alaska 99503

[1]Reprint Address: 2950 Fritz Cove Rd., Juneau Alaska 99801

[2]Present Address: LGL Ltd., 2453 Beacon Avenue., Sidney, B.C.

[3]Present Address: School of Fisheries & Science, University of Alaska, Juneau, AK

[4]Present Address: Archipelago Marine Research, 5 Helmcken Rd., Victoria, B.C.

SUMMARY

In summer, the fish community of Simpson Lagoon and adjacent coastal waters of the Beaufort Sea was dominated by two marine species (Arctic cod, fourhorn sculpin) and three anadromous species (Arctic and least cisco, Arctic char). The anadromous species remained in the relatively warm and brackish waters near shore and demonstrated an affinity for shoreline edges, particularly the mainland shoreline where species occurrence and catch per unit effort (CPUE) were highest. Spatial segregation was low, presumably reflecting the migratory nature of these species. Marine species were less restricted to nearshore waters in summer and were typically the only species present in winter because anadromous species return to rivers, lakes and deltas to spawn and overwinter. Winter CPUE was 10U and consisted primarily of Arctic cod and fourhorn sculpin.

INTRODUCTION

The nearshore environment along the Alaskan Beaufort Sea coastline provides important habitat for several arctic fishes, including *the* anadromous species utilized by man. During the short arctic summer, anadromous and marine fishes invade previously frozen nearshore waters and feed extensively on a plentiful supply of epibenthic invertebrates (Craig *et* al. 1984). The fish accumulate food reserves for spawning or overwintering requirements.

Information about fish resources is accumulating in conjunction with exploration for Beaufort Sea oil and gas (reviewed by Craig 1984), but few detailed accounts have been published. The present study examines the species composition and distribution of fishes utilizing this nearshore zone.

STUDY AREA

Summer studies were conducted in Simpson Lagoon, located between Prudhoe Bay and the Colville River delta on Alaska's North Slope (Fig. 1). The lagoon is a large and partially enclosed *body* of brackish water 35 km long and 3-6 km wide, with an average depth of only 2 m (maximum 3 m). The lagoon floor is uniformly flat and almost featureless. In most areas, a layer of detritus covers substrates of mud and sand.

The short ice-free period in the lagoon lasts from early July to early October. Tidal fluctuations are small (10-15 cm). Summer salinities (l-32 ppt), temperatures (0-14°C) and turbidities (1-146 NTU)

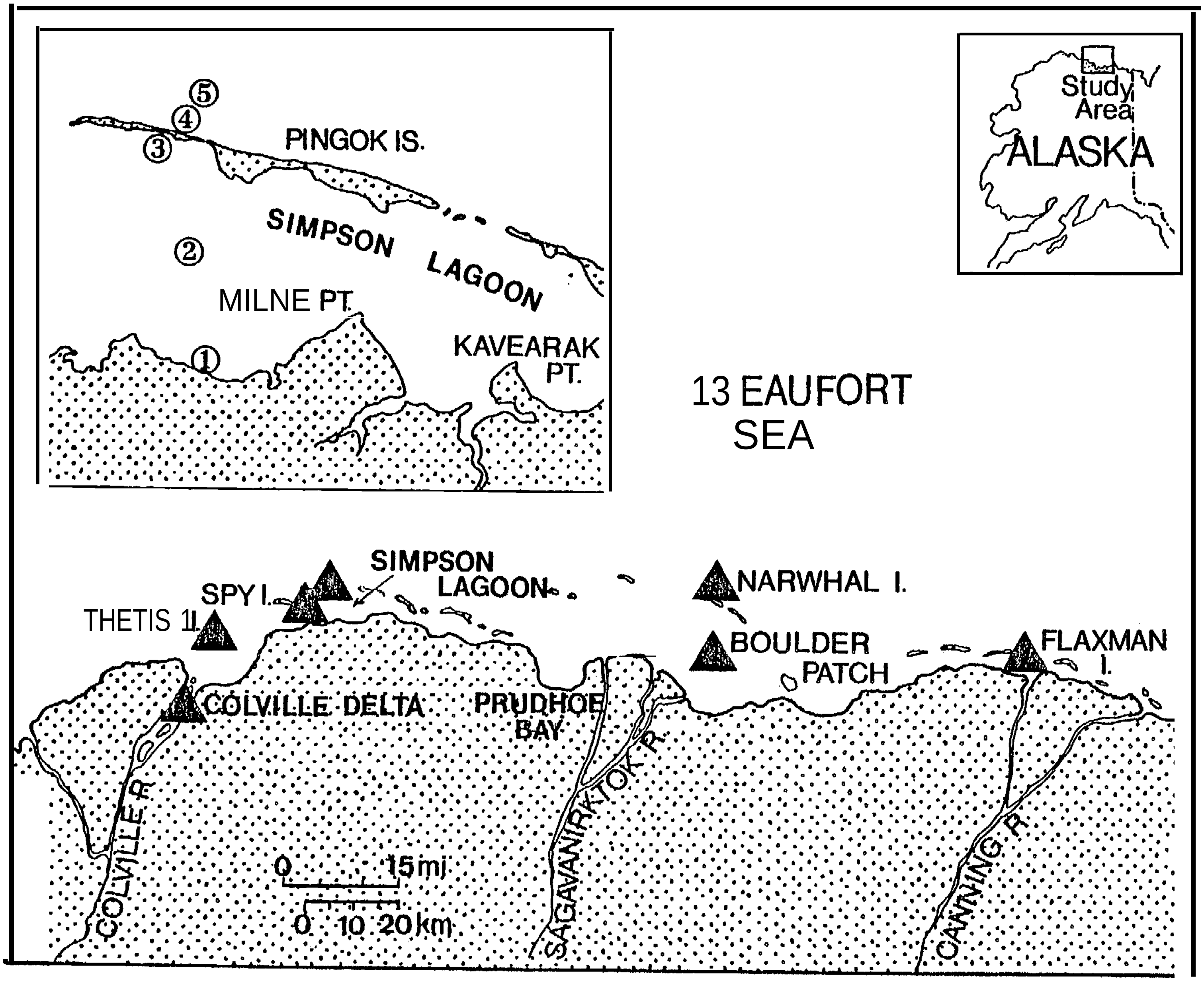

Figure 1. Locations of summer sampling Stations 1-5 in Simpson Lagoon area and nearshore winter sites (triangles); the 175 km offshore site is not shown.

fluctuate as a direct influence of the prevailing westward flowing Beaufort Sea current, wind, and freshwater runoff. Lagoon waters are diluted by freshwater runoff and are correspondingly lower in salinity (4-5 ppt) and higher in temperature (2-4°C) than waters seaward of the barrier islands (Fig. 2). This difference is less marked late in summer as runoff declines. Prevailing westward currents exchange lagoon water at an average rate of 10-20%/day, with 100%/day flushing during exceptionally strong winds (65 km/h) (Mungall 1978). During the winter, exchange diminishes as surface ice steadily increases in thickness to about 2 m. By late winter 90% of the lagoon volume is frozen solid, and hypersaline conditions (up to 68 ppt, Crane 1974) develop from salt exclusion during ice formation.

Winter studies were conducted in Simpson Lagoon as well as other nearshore and offshore locations between the Colville and Canning rivers (Fig. 1). Additional details about the study area appear in Craig and Haldorson (1981).

METHODS

Summer Programs

Studies in Simpson Lagoon were conducted throughout the open-water seasons of 1977 and 1978. Fish were sampled by gill net at five stations (Fig. 1) in 1977. Because gill nets selectively catch the larger size classes of fish, additional gear (beach seine, fyke net, plankton net) were used to examine fish distributions.

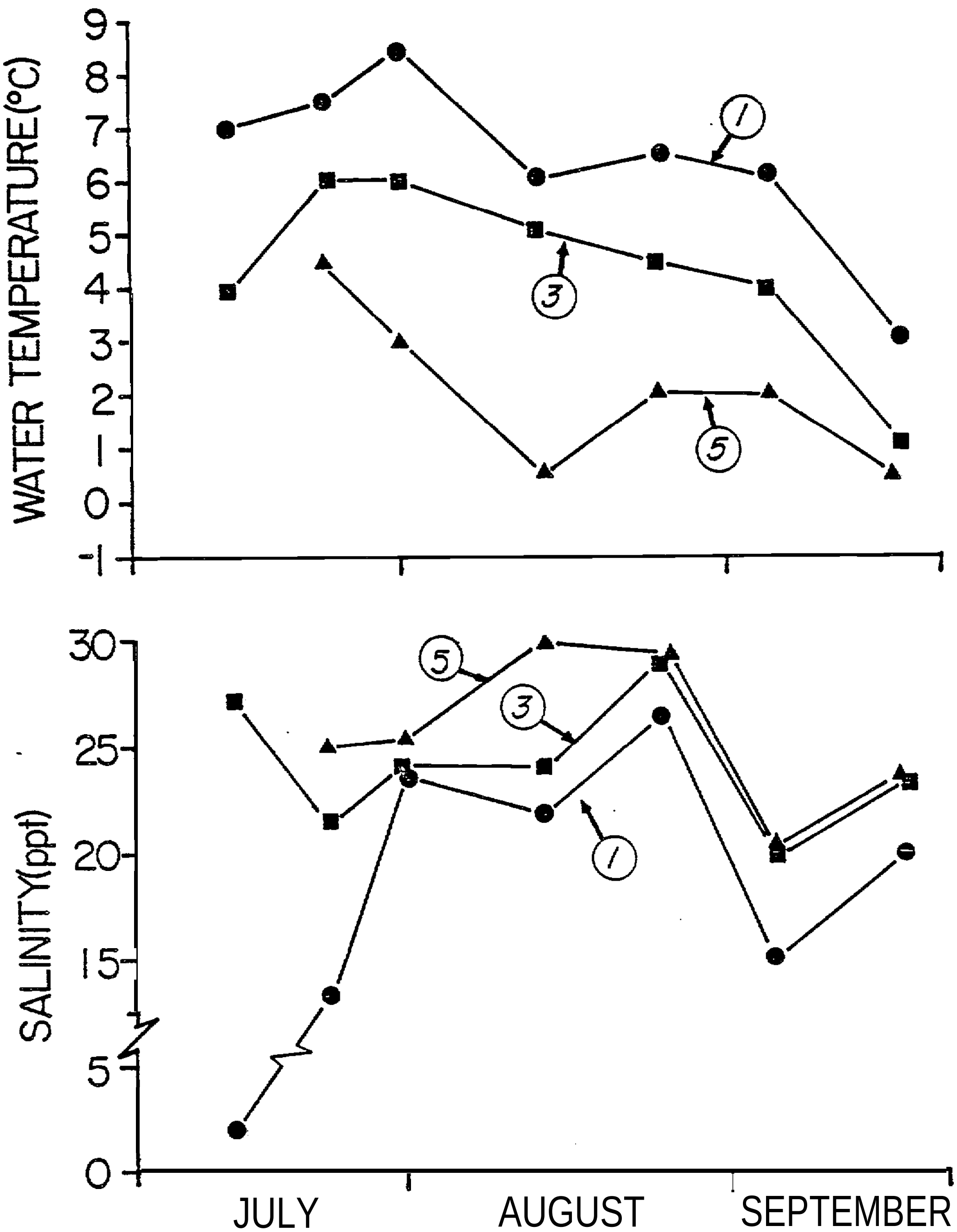

Figure 2. Surface water temperatures and salinities at Stations 1, 3 and 5, Simpson Lagoon, 1977.

Gill nets used at all stations measured 47.2 m long and 2 m deep with variable mesh panels (2.5, 3.8, 5.1, 6.4 and 8.9 cm stretched mesh). In shallow waters at Stations 1-4, this net sampled the entire water column; both sinking and floating gill nets were used in deeper (10 m) waters at Station 5. Stations were first sampled on 24 June 1977 soon after the ice melted and thereafter at 5-12 day intervals until 18 September 1977. Gill net sets were usually 24 h in duration but sometimes varied (from 10-120 h) when ice and weather renditions interrupted the normal routine.

A longer gill net (122 x 2 m) was used 24 July-9 September 1978 to determine the micro-distribution of fish along the shoreline. This net had a single mesh size (5.1 cm) which was particularly effective in catching char and ciscoes in coastal waters (Griffiths et al. 1975). The net was set perpendicular to the shoreline with a2-3 m gap between net and shoreline so that fish trying to avoid the net would not be funneled into the net at the shoreward end. The net was marked at2-m intervals so that the locations of captured fish could be recorded. Water depths were typically 0.3 m at the landward end of the net and 1.5 m at the seaward end. Sets were brief (usually 1-3 h) because of the effectiveness of the net at catching fish and to minimize the possibility that fish would avoid areas where many fish were already caught. Eight sets were made off points of land (e.g., Milne Point), seven in moderately calm weather and one in rough weather. An additional set was in an embayment between Milne and Kavearak points where a transect longer than 122 m was sampled by sequentially resetting the net at increasing distances of 122 m farther offshore for equal time periods.

Fyke nets were set perpendicular to the shoreline with the lead net attached to the shore. Mesh sizes (stretched) were 1.2 cm for the trap and 2.5 cm for lead and wing nets. In 1977, the lead net was 33.3 m long and wing nets were 7.6 m. Fyke nets were established at Stations 1 and 3 on 25-27 July 1977 and operated almost daily until 22 September 1977. In 1978, the fyke net was enlarged (66.7 m lead net, 15.2 m wing nets), and it operated almost the full length of the open-water season (30 June-24 September 1978) at Milne Point. The larger fyke net appeared to be more effective than the 1977 version; more fish and a wider size range of fish were caught.

A modified Faber net (Faber ?968) with a 0.5 m diameter and 1.0 mm mesh was used to catch planktonic fish. Each tow filtered approximately 82 m^3 of surface water (i.e., a 4-min tow at 1.4 m/s). Values presented are the average of two replicate tows at each sampling site.

A 91.4 m beach seine was used to estimate numbers of fish in the usually turbid shoreline waters. While one end of the net was held onshore, the seine was set by boat in a curve, returning to shore approximately 35 m down the beach from the starting point. The area swept by the seine was approximately 1000 m2 (Craig and Haldorson 1981).

Winter Programs

Under-ice sampling was conducted during three winters. Sites included the Colville Delta (April-May 1978), several nearshore sites between the Colville Delta and Flaxman Island near Prudhoe Bay (November 1978, February, March, April, and November 1979, May 1980), and one offshore site located 175 km north of Prudhoe Bay (May 1980).

Difficulties in collecting fish in ice-covered areas necessitated the use of a variety of nets during winter studies. Gill nets (47.2 m long with various combinations of stretched mesh sizes ranging from 1.9-8.9 cm) and fyke nets (with four 27.4-m lead nets and common trap) were the principal gear used. Fyke nets were baited with fish or light, or unbaited, and set at or near the bottom of the water column to avoid freezing to the under-ice surface except at the deep offshore station where the fyke net was set directly under the ice. Details of net types and time flushed are presented in Craig and Haldorson (1981). The overall winter sampling effort in coastal waters was extensive: gill nets (252 days fished), fyke nets (62 days), minnow traps (14 days), trammel nets (10 days), and box trap (1 day).

Physical and Chemical Measurements

Water Temperature and salinity (YSI-33 Salinity/Conductivity meter) were measured at approximately 10-day intervals at Stations 1-5.

RESULTS

Fish Populations in Simpson Lagoon

During summer and winter sampling periods, almost 200,000 fish of 23 species were caught in or near Simpson Lagoon (all but subsamples were released alive). These are listed according to their principal life history pattern:

Anadromous Species
- Arctic char (Salvelinus alpinus)
- Arctic cisco (Coregonus autumnalis)
- least cisco (C. sardinella)
- Bering cisco (C. laurettae)
- broad whitefish (C. nasus)
- lake (humpback) whitefish (C. clupeaformis)
- rainbow (boreal) smelt (Osmerus mordax)
- ninespine sticklebacks (Pungitius pungitius)
- pink salmon (Oncorhynchus gorbusca)
- chum salmon (O. keta)
- sockeye salmon (O. nerka)
- threespine sticklebacks (Gasterosteus aculeatus)

Marine Species
- Arctic cod (Boreogadus saida)
- fourhorn sculpin (Myoxocephalus quadricornis)
- Arctic flounder (Liopsetta glacialis)
- saffron cod (Eleginus gracilis)
- capelin (Mallotus villosus)
- Pacific herring (Clupea harengus)
- snailfish (Liparus sp.)
- sculpin (Myoxocephalus sp.)
- Pacific sand lance (Ammodytes hexapterus)

Freshwater Species
- round whitefish (Prosopium cylindraceum)
- grayling (Thymallus arcticus).

Three of these species are outside their reported ranges by several hundred kilometers; the threespine sticklebacks and sockeye salmon have not been recorded previously in Beaufort Sea waters, and the Pacific sand lance has apparently not been collected between the Chukchi Sea and Herschel Island, Yukon Territory (McAllister 1962, McPhail and Lindsey 1970, Hart 1973, Scott and Crossman 1973).

Summer Distribution Patterns

Five species accounted for over 91 and 99% of all fish caught (excluding ichthyoplankton) during the summers of 1977 and 1978, respectively; two marine species (Arctic cod, fourhorn sculpin) were the numerical dominants in the lagoon, followed by three anadromous species (Arctic cisco, least cisco, Arctic char). The relative abundance of fishes in Simpson Lagoon varied according to method of capture (Table 1). The fyke net data are of particular interest because the majority of fish caught by this method were small Arctic cod, fourhorn sculpin and Arctic cisco. These data and the results of others (Bendock 1979, Griffiths et al. 1983, Griffiths and Gallaway 1982) show that small fish are substantially more common in nearshore Beaufort Sea waters thsn indicated by earlier studies that relied on data obtained by gill nets (reviewed by Craig and McCart 1976).

Fish numbers and composition in Simpson Lagoon changed markedly between the two years of study. In 1978, all species found in 1977 were collected and eight additional species were encountered. There was also a small run of pink salmon in Simpson Lagoon during 1978, whereas during 1977 no salmon were caught. The tremendous numbers of Arctic cod (estimated in the millions) that entered Simpson Lagoon in mid-August of 1978 constituted the most important difference between years. The actual 1978 catch of about 140,000 Arctic cod was approximately 14 times larger than the total number of' all fish caught during the previous summer. In fact, on four separate occasions in 1978, the daily catch of Arctic cod

Table 1. Relative abundance of fishes caught by different methods during the open-water season in Simpson Lagoon.

Fish Species	1977 Gill Net %	1977 Fyke Net %	1977 Plankton Net %	1978 Beach Seine %	1978 Fyke Net %
Arctic cod	●	8	84	8	78
Fourhorn sculpin	9	70	0	21	18
Arctic cisco	56	15	0	17	1
Least cisco	12	2	0	48	1
Arctic char	14	4	0	4	1
Broad whitefish	4	●	0	1	*
Humpback whitefish	2	0	0	0	*
Arctic flounder	●	1	0	1	*
Rainbow smelt	0	*	0	1	*
Saffron cod	0	0	0	0	*
Bering cisco	1	0	0	0	*
Capelin	1	●	0	0	*
Pink salmon	0	0	0	*	*
Ninespine sticklebacks	0	*	0	0	*
Pacific herring	0	0	0	0	*
Snailfish sp.	0	●	17	*	*
Grayling	0	0	0	0	*
Chum salmon	0	0	0	0	*
Sculpin sp.	0	0	*	●	0
Threespine sticklebacks	0	0	0	0	*
Pacific sand lance	0	0	0	0	●
No. fish caught	781	10,026	366	450	179,487
% anadromous fish	89	21	0	70	3

● <0.5%.

exceeded the total 1977 catch. Between-year differences in sampling methods undoubtedly affected the size and species composition of the catch, but the data demonstrate that fish numbers and relative abundance in the lagoon-barrier island ecosystem may fluctuate dramatically from year to year. However, if numbers of Arctic cod are excluded from catch records, proportions of most other species were roughly similar during the two summers.

The dominance of the abundant, but small-bodied, marine species in the lagoon is less pronounced when the nearshore fish assemblage is described in terms of biomass rather than numbers. In 1978 when anadromous fish accounted for only 3% of the fyke net catch, biomass calculations {numbers x average weight per species) indicate that anadromous fish comprised almost half (46%) of the total fish biomass in the lagoon (Fig. 3).

Since *the* young of arctic anadromous species tend to spend one or more years in freshwater before entering coastal waters, the ichthyoplankton of coastal waters is comprised primarily of marine species. particularly Arctic cod and snailfish (Table 1).

Nearshore Distribution

During the 1977 gill net program, far more fish were caught per unit effort in lagoon habitats than in marine habitats (Fig. 4, Table 2). This difference is even more apparent if the seaward shoreline of the barrier islands is considered to be anearshore habitat since this shoreline is a

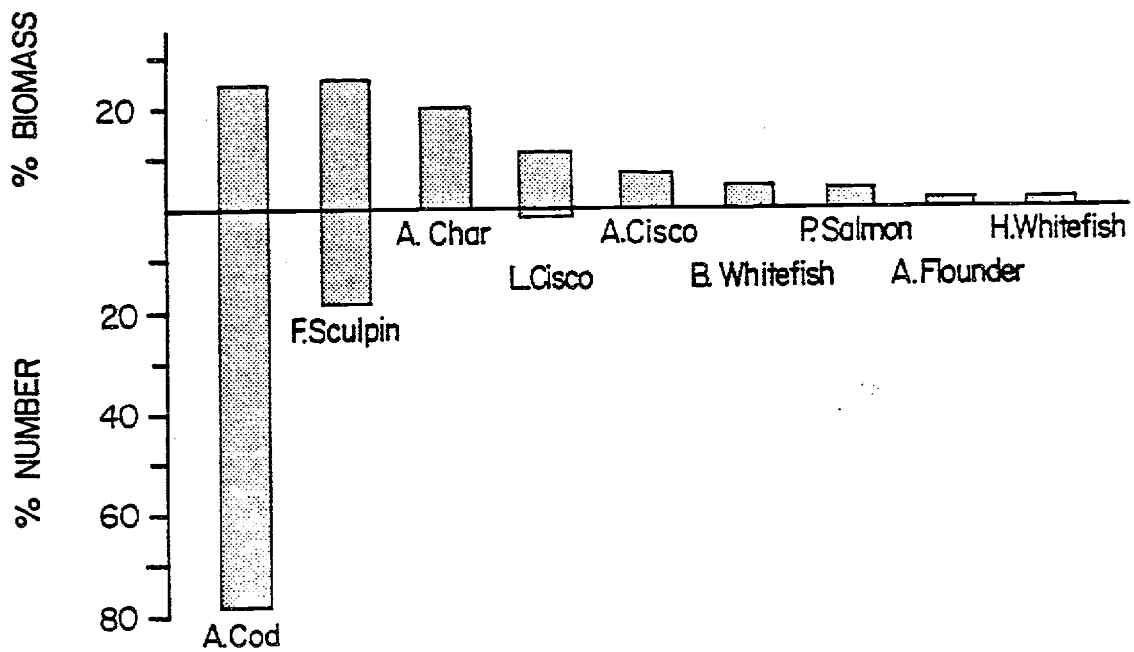

Figure 3. Relative abundance and biomass of fish in Simpson Lagoon (1978 fyke net catch of 179,487 fish with an estimated biomass of 5405 kg).

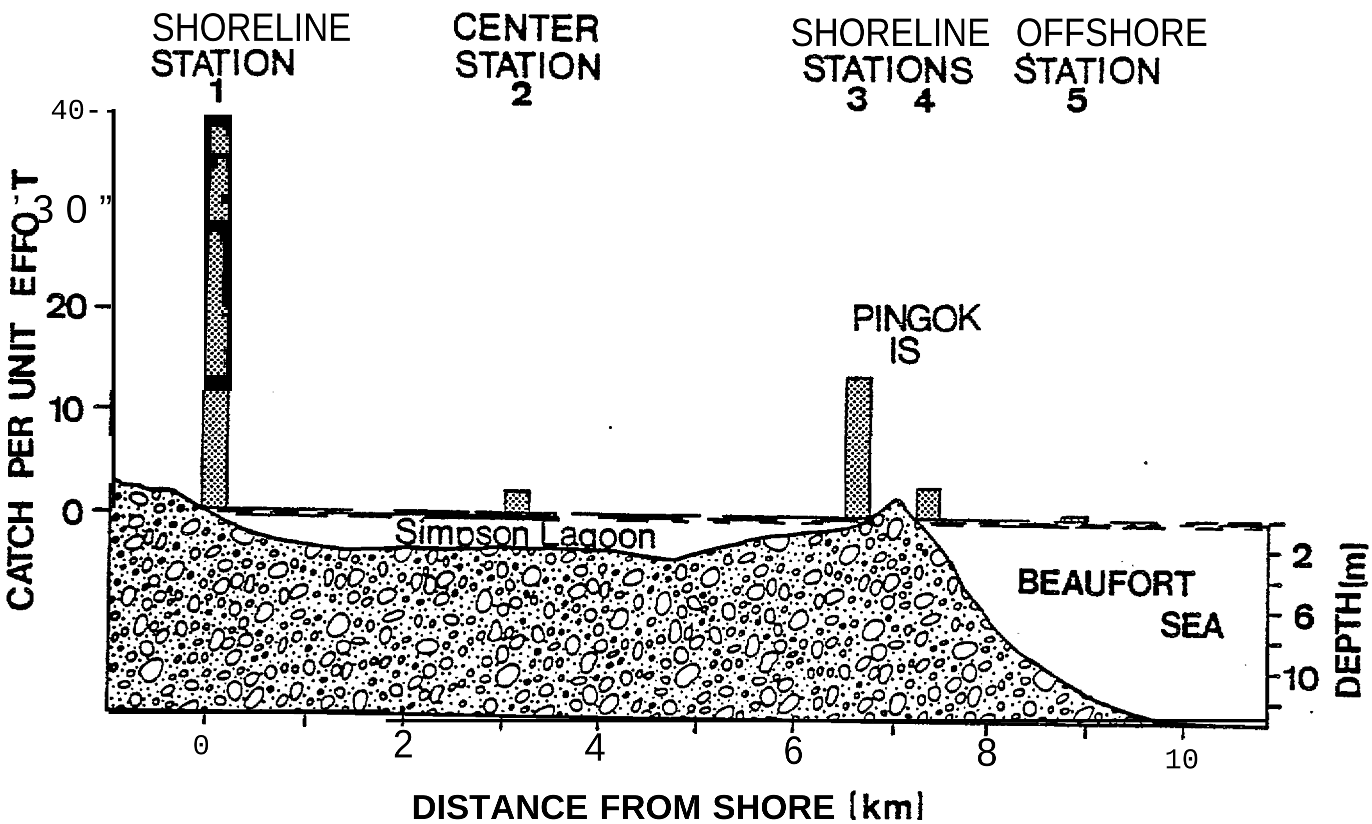

Figure 4. Catch per unit effort (CPUE) of fishes at five sampling stations in Simpson Lagoon area; CPUE is the seasonal average/24 h gill net set.

Table 2. Seasonal averages of catch per unit effort (CPUE) for fishes caught by gill net at five sampling locations during the open-water season, 1977. (See Fig. 1 for locations.)

Fish Species	Seasonal CPUE (No. fish/24 h) Sta. 1	Sta. 2	Sta. 3	Sta. 4	Sta. 5	Comparison of Stations 1-4 (Friedman test)
Arctic cisco	17	1.1	9	0.1	0	<0.02*
Least cisco	8.1	0	0.7	0	0	<0.01
Arctic char	5.9	0.4	3	2.1	0	<0.2
Fourhorn sculpin	3.4	0.5	0.8	1	0.1	<0.1
Broad whitefish	3	0	0	0	0	<0.02
Humpback whitefish	1.6	0	0	0	0	<0.01
Arctic flounder	0.2	0	0	0	0	<0.1
Capelin	0	0.1	0.8	0.1	0	<0.1
Snailfish	0	0	0.1	0	0.2	
Arctic cod	0	0	0	0	0.1	
All anadromous spp.	35.6	1.5	12.7	2.2	0	<0.01**
All marine spp.	3.6	0.6	1.7	1.1	0.4	<0.1
Totals	39.2	2.1	14.4	3.3	0.4	
No. sets	10	10	10	7	7	
No. days fished	10	19	10	10	10.5	

* Friedman critical value test indicates that numbers of fish at Station 1 are significantly greater than Station 4 ($P < 0.01$).

**Station 1 > 2 and 1 > 4 at $P < 0.04$.

flooded by brackish lagoon waters when east winds pull the lagoon water mass out through the gaps between the barrier islands. On a catch per unit effort basis, fish were 5 to 98 times more abundant at various nearshore stations than at the one offshore station. Nearshore catches ranged from a high of 39.2 fish/24 h (species combined, seasonal average) along the mainland shoreline to a low of 2.1 fish/24 h in the lagoon center. In contrast, the average catch in offshore gill nets was only 0.4 fish/24 h, and, significantly, no anadromous species were caught.

Within the nearshore brackish water region, it is apparent that fish were not uniformly distributed but were more abundant along mainland and island shorelines than in the lagoon center. Seasonally averaged catches along the mainland shoreline were 19 times greater than in the lagoon center. Although fish catches along all shorelines in the study area were higher than in open-water areas, the mainland shoreline was used more extensively and by more species of fish than island shorelines. For most species except fourhorn sculpin, numbers of fish at nearshore Stations 1-4 were significantly different (Table 2), although only a single difference among stations could be determined using critical values based on Friedman rank sums (Hollander and Wolfe 1973). However, an inspection of Table 2 shows that species were *consistently* most abundant at Station 1, and when all anadromous fish were combined, there were significantly more fish at Station 1 than at either Station 2 or 4 ($P < 0.04$).

Data obtained in 1978 by different sampling gear (91.4 m beach seine) followed the same pattern. Fish densities along the mainland shoreline (0.0095 fish/m^2, species combined] were far greater than at other shoreline locations (Table 3). Relative numbers of fish caught along the three shoreline habitats were very similar during the two years of' study, especially if small fish (i.e., char and whitefish <200 mm, sculpin <100 mm) are excluded from the 1978 beach seine data since these size classes of small fish are not often caught by gill nets:

	Method	Relative Number Caught		
		Island Shore (Ocean Side)	Island Shore (Lagoon Side)	Mainland Shore
1.	gill net (1977)	1	4	12
2*	beach seine (1978) ("large" fish only)	1	6	18
3.	beach seine (1978? (all fish)	1	6.5	24

Data obtained from fyke nets corroborated the difference in fish catches between mainland and island shorelines (Table 4). In 1977, the average catches in 24 h were 160 fish at the mainland site and 104 fish at the island site (lagoon side of Pingok Island). Numbers of most species were highest along the mainland shoreline, and these differences were statistically significant for all species compared except fourhorn sculpin.

Affinity for the mainland shoreline varied among species, as previously noted by Bendock (1979). Least cisco, broad whitefish and humpback whitefish in Simpson Lagoon were not commonly taken anywhere but in the relatively warm and brackish waters along the mainland (Tables 2 to 4). Arctic cisco and Arctic char were distributed more widely and more commonly present along the lagoon side beaches of the barrier islands.

Table 3. Beach seine data for mainland and barrier island shorelines during the open-water season, 1978.

Fish Species	Seasonal Averages of Fish/Seine Haul — Mainland	Island Lagoon Side	Island Ocean Side
Least cisco	4*9 (20)*	0.1 (1)	
Fourhorn sculpin	2.0 (17)	0.4 (3)	0.1 (1)
Arctic cisco	1.4 (16)	1.2 (3)	
Arctic cod	0.8 (6)	-	
Arctic char	0.1 (3)	0.9 (4)	0.3 (1}
Broad whitefish	0.1 (4)		
Rainbow smelt	0.1 (2)		
Arctic flounder	0.1 (3)		
Pink salmon	0.02 (1)		
Sculpin sp.	0.02 (1)		
Snailfish sp.		0.1 (-l)	
All anadromous spp.	6.;	2.2	0.3
All marine spp.	2.9	0*5	0.1
Totals	9.5	2.6	0.4
Density (fish/m^2)	0.0095	0.0027	0.0004
No. seine hauls	44	11	8

*Parentheses indicate number of seine hauls in which each species was caught.

Table 4. Comparison of fyke net data for mainland and Pingok Island sites, 8 August to 21 September 1977.

Fish Species	Mean Catch in Fyke Net/24 Hour: Mainland Shoreline (Station 1)	Mean Catch in Fyke Net/24 Hour: Island Shoreline (Station 3)	Paired Comparison (Wilcoxon test)
Fourhorn sculpin	92	94	P = 0*1
Arctic cisco	36	6	P <0.001
Arctic cod	15	4	P < 0.01
Arctic char	8	1	P < 0.05
Least cisco	5	0.03	P < 0.01
Arctic flounder	3	0.07	P < 0.01
Smelt	0.6	0.07	
Ninespine sticklebacks	0.4	0.07	P < 0.02
Broad whitefish	0.3	0	P < 0.05
Snailfish	0*1	0.03	
Capelin	0	0.07	
All anadromous spp.	50	7	P < 0.001
All marine spp.	110	98	P = 0.07
Total	160	105	
Daily range	(2-626)	(0-810)	
Fishing effort (days)	36	30	

Arctic char were the most abundant anadromous fish along the seaward beaches of the barrier islands. Bendock (1979) reports that Arctic char have been caught as far offshore as Cross Island which is about 18 km offshore.

The fourhorn sculpin was distributed more evenly through the study area than were other species. Fyke net data (Table 4) showed sculpins to be equally abundant along mainland and barrier island (lagoon side) beaches; beach seines showed them to be most abundant along the mainland, although this difference was not statistically significant (Friedman test, $P > 0.2$).

Proximity to the Shore

The distribution of fish relative to distance from shore was examined by recording positions of fish caught in a 122 m gill net placed perpendicular to the shoreline with a 2-3 m gap between the net and the shoreline (see METHODS). Seven sets made off points of land in moderately calm weather caught a total of 117 least cisco, 52 Arctic char, 45 Arctic cisco, 18 fourhorn sculpin, 4 broad whitefish and 4 humpback whitefish. On these occasions, there was a very narrow band of fish adjacent to the shoreline (Fig. 5) under the following conditions: (1) the water was not exceptionally rough, and (2) the sampling location was at or near a prominent land projection into the lagoon (e.g., Milne Point or Kavearak Point) where water depths fell more rapidly than in shallow embayments. Approximately six times as many anadromous fish were caught in the first

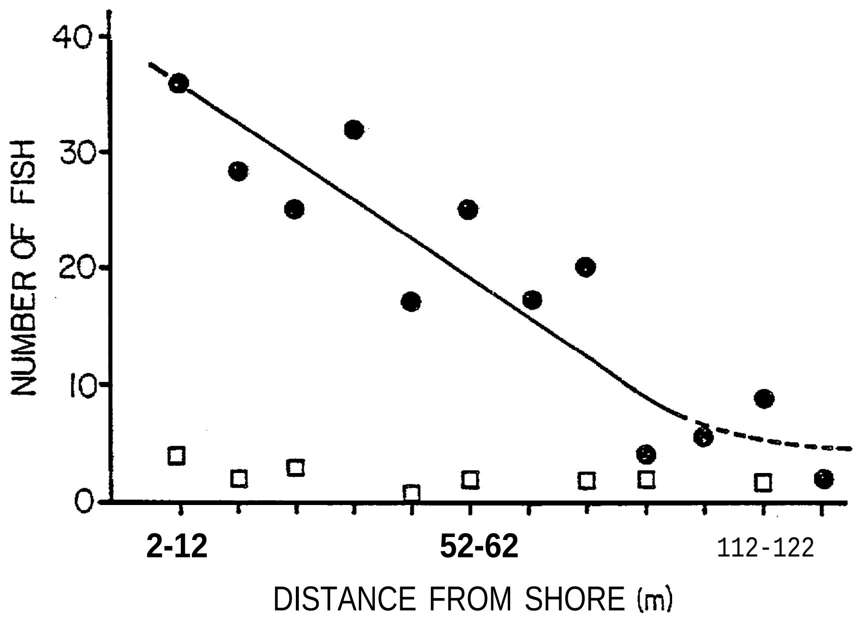

Figure 5. Abundance of anadromous fishes (circles) and fourhorn sculpin (squares) in relation to distance from shore under selected circumstances (see text).

(landward) 40 m of net as were caught in the last (seaward) 40 m. Numbers of anadromous fish caught in three distances from shore categories, 0-40 m, 40-80 m, and 80-120 m, were significantly different (Friedman two-way analysis of variance, $P < 0.02$) with numbers of fish at 0-40 m being significantly greater than numbers at 80-120 m ($P < 0.02$). The abundance of anadromous fish declined steadily with distance from shore out to about 100 m, at which point numbers presumably leveled off. Data from 1977 (Fig. 4) suggested that low densities would continue across the center of the lagoon. Unlike the anadromous species, the fourhorn sculpin was uniformly distributed throughout this area.

Among the anadromous species, there was a conspicuous absence of spatial segregation within 122 m of shore (Fig. 6), presumably reflecting the migratory nature of these species. Indeed, it has been observed that Arctic cisco and Arctic char may form mixed schools (Griffiths et al. 1975:99).

There are times and places where the shoreline concentration of fish does not occur. We encountered two examples during 1978. During a stormy period with rough waters, most fish caught were several hundred meters offshore at Milne Point (Fig. 7). On another occasion gill nets set along a transect in a very shallow embayment between Milne and Kavearak points caught no fish near the shoreline, but some fish were taken 1.6 km offshore. Preliminary netting also indicated that the shoreline distribution of fish was influenced by underwater topographical features such as submerged sand and gravel bars, which characteristically form 100-

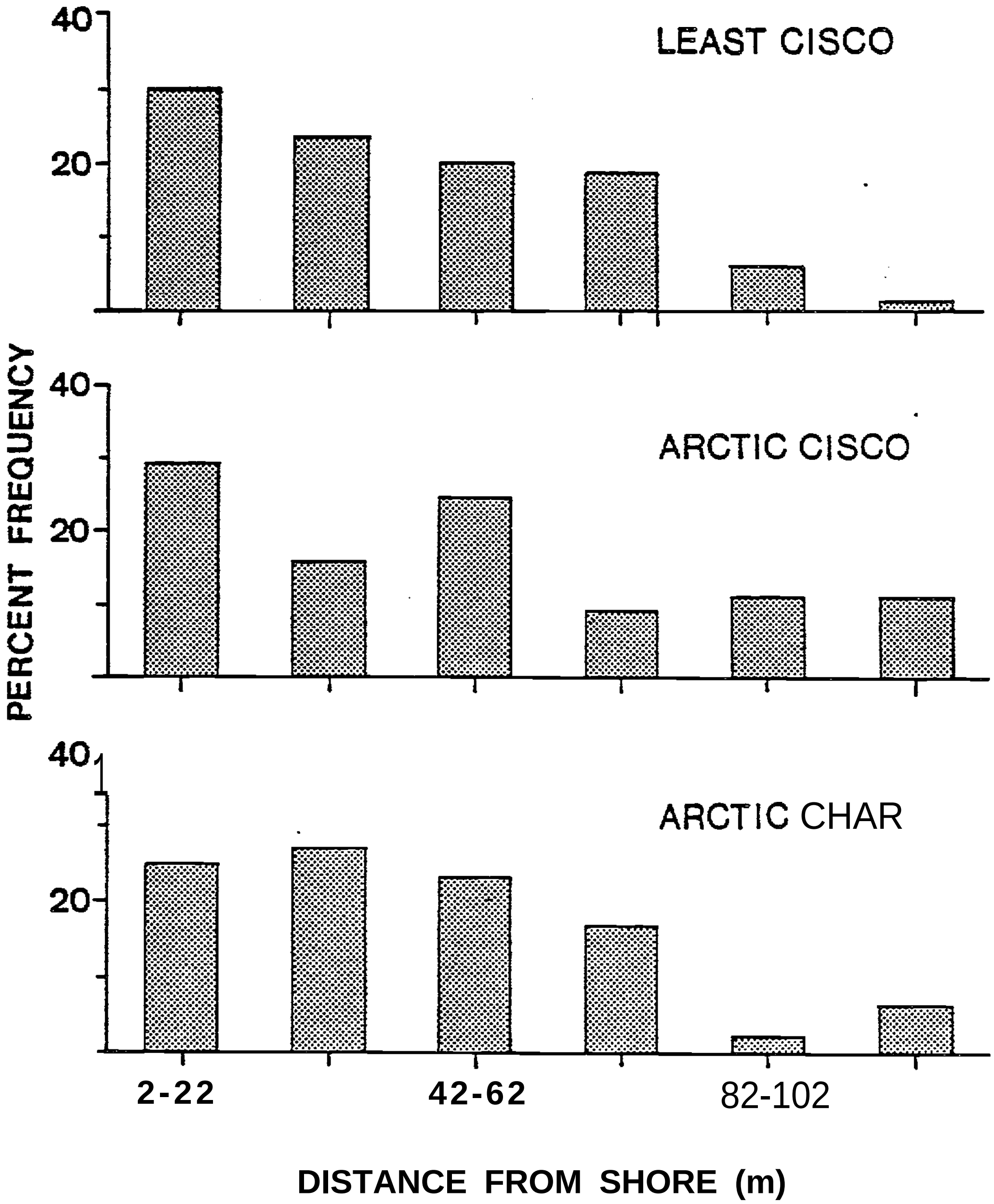

Figure 6. Distribution of three anadromous fishes in relation to distance from shore under selected circumstances (see text) .

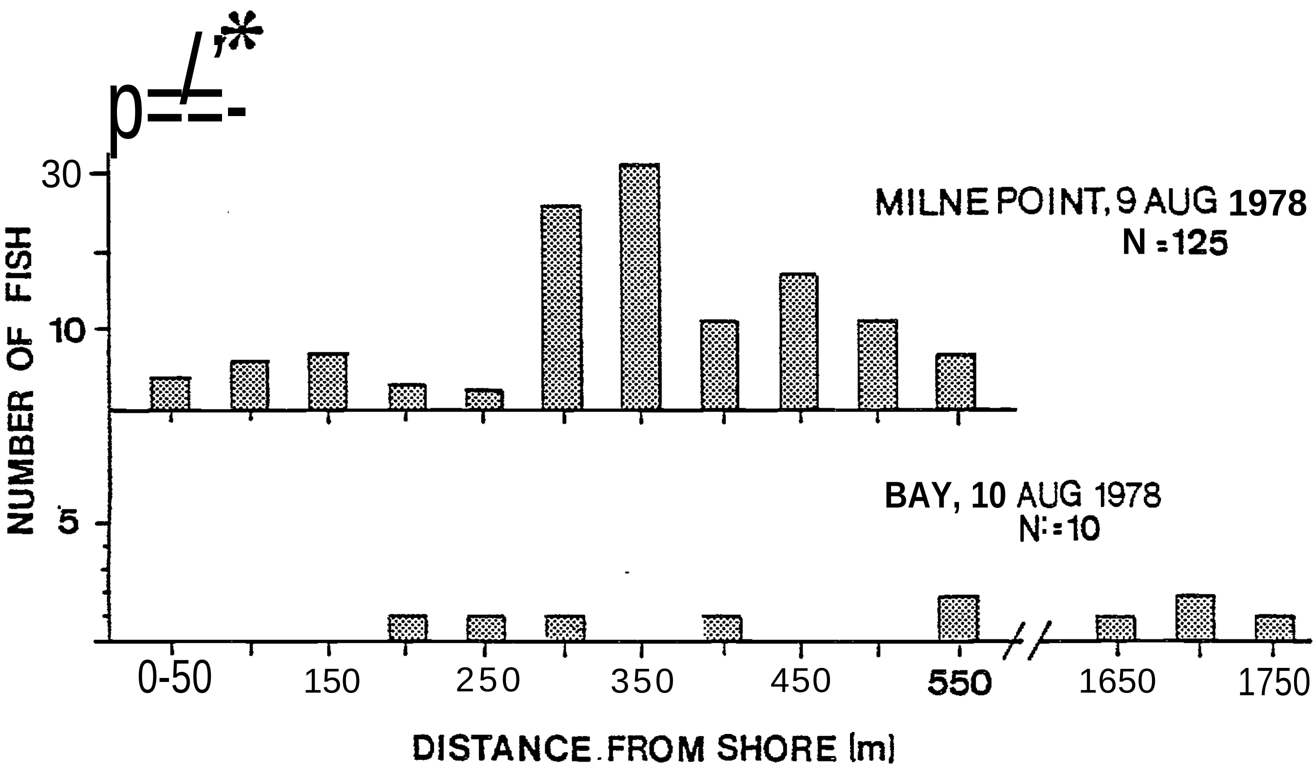

Figure 7. Dispersed distributions of anadromous fishes during rough-water conditions (top) and in a relatively shallow bay between Milne and Kavearak points (bottom; no nets were set between 550 and 1650 m). The frequent location of the shoreline concentration of fish (Fig. 5) is indicated by asterisk.

400 m offshore on the west side of points of land in the study area. Although comparative netting was not performed, it appeared that fish were more abundant around these bars than might have been predicted on the basis of distance from shore alone.

Winter Distribution Patterns

In winter, virtually all anadromous species vacated the nearshore marine environment and returned to rivers, lakes and deltas to spawn and/oroverwinter. Winter catches at most coastal locations consisted primarily of marine species: Arctic cod, fourhorn sculpin, snailfish, saffron cod and Arctic flounder (Table 5). Additional marine species were presumably present but not collected due to gear selectivity. The rainbow smelt was the only anadromous species collected in coastal waters.

The overall catch rate in winter was very low. Off the Colville River where rainbow smelt and fourhorn sculpin were relatively abundant, the under-ice catch rate averaged 26.4 fish (species combined) per 24 h gill or fyke net set. At other coastal locations, the average was *only* 1.4 fish/24 h (Table 6). This low CPUE was obtained despite an extensive sampling effort in early, mid and late winter periods at seven sites spread across 120 km of coastline (Table 6). Gear selectivity and reduced activity of fishes because of cold water temperatures in winter (usually -1 to 0°C) may have contributed to these low catches.

The winter sampling effort did demonstrate some distributional differences among coastal fishes. A pre-spawning aggregation of rainbow

Table 5. Summary of winter catch data, 1978-1980.

	% Composition in Winter		
	Coastal Locations		
Fish Species	Combined coastal Sites**	Thetis Island Area	Colville Delta
Arctic cod	59		
Fourhorn sculpin	20	39	9
Rainbow smelt	14	59	14
Snailfish	7	*	
Saffron cod		1	1
Arctic flounder		*	
Arctic cisco			45
Least cisco			28
Bering cisco			3
No. fish caught	260	2610	150
Total effort (net-day)	183	99	57
CPUE (No. fish/day)	1.4	26.4	2.6

* <0.5%.
**Excluding Thetis Island.

Table 6. Winter catches of fishes in Beaufort Sea coastal waters. Average catch per unit efforts (CPUE) are listed for combined sampling periods for fish caught by net (principally gill and fyke nets but also trammel net and box trap) per day.

Date	Fish Species	Average CPUE (Fish/Net-day) Thetis Island	Spy Island	Simpson Lagoon	Boulder Patch	Narwhal Island	Flaxman Island	175 km Offshore**
Early Winter								
(13-16 November 1978	Rainbow smelt	13.3		0.8	0	0	0	
4-15 November 1979)	Fourhorn sculpin	1.0		0.2	*	0	3.5	
	Arctic ood	0.7		0.6	0.5	1.0	4.5	
	Saffron cod	0		0	0	0	0	
	Snailfish	0		0	0.1	0	0	
	Total effort (days)	14	0	44	33	2	2	0
Mid-winter								
(11-27 February 1979)	Rainbow smelt	22.2		0	0	0		
	Fourhorn sculpin	6.8		0	0	0		
	Arctic cod	0		0	3.7	0		
	Saffron ood	1.0		0	0	0		
	Snailf ish	0		0	1*1	0		
	Total effort (days)	20	0	7	14	16	0	0
Late Winter								
(1 March-1 April 1979	Rainbow smelt	14.0	0.2	0	0	0	0	0
29 April-14 May 1979	Fourhorn sculpin	11.0	0.3	0	0	0		0
29 April-6 May 1980)	Arctic cod	0	0	0	0,4	0.5		10.8
	Saffron cod	0.1	0	0	0	0		0
	Arctic flounder	*	0	0	0	0		0
	Total effort (days)	65	10	10	24	15	0	6
Approximate late winter water depth (m)		1.7	3.3	0.5	4.6	10.0	0.5	2,500+

* <0.05 CPUE.

** Location 71°49.7'N, 148°22.6'W.

smelt was present near Thetis Island-. these fish presumably spawn in the Colville River in springtime (Haldorson and Craig 1984). Arctic cod were common in nearshore waters but their highest CPUE occurred farther offshore as described by Craigetal. (1982). Fourhorn sculpin were caught at most locations and they increased in abundance through the winter near Thetis Island off the Colville River. Snailfish were collected only at the Boulder Patch site off the Sagavanirktok River. The Boulder Patch (Dunton et al. 1982) is one of the few coastal locations with a rocky bottom and it presumably provides habitat for marine species which spawn on hard substrates. Shallow water habitats such as Simpson Lagoon provide winter habitat for fishes only during early winter--by late winter the sea ice freezes to a depth of about 2 m thereby freezing solid much of the coastal habitat which received extensive use in summer.

Overwintering fish were collected at one additional site, the brackish waters (18-32 ppt) of the lower Colville River delta. Both anadromous and marine species were collected under the ice in the delta (Table 6). These catches indicate that the ciscoes do not necessarily reside in freshwater habitats during the winter period but have a tolerance of saline water in winter (Table 5); however, no ciscoes were found in nearby coastal waters during extensive winter surveys. To date, no ciscoes have been caught in coastal waters in winter except in Siberia (Berg 1957) and off the outer delta of the Mackenzie River in Canada (e.g., Bond 1982).

DISCUSSION

The anadromous and marine fishes of Simpson Lagoon are representative of the fish fauna in nearshore waters of the Beaufort Sea (summarized by Craig 1984). Their use of the lagoon is primarily for feeding on the lagoon's abundant supply of epibenthic invertebrates (Griffiths and Dillinger 1981, Craig et al. 1984). The lagoon also serves as a migratory pathway for the anadromous species which enter the Beaufort Sea each spring and disperse along the coastline in summer; these species return to freshwater in fall to spawn and overwinter.

During the open-water season, two prominent trends describe the distribution of anadromous fishes in Simpson Lagoon: (1) most fish inhabited nearshore brackish waters rather than offshore marine waters, and (2) within the brackish waters, fish numbers were highest along shoreline edges, particularly the mainland shoreline. These generalizations are less applicable for marine species which are not restricted in distribution to nearshore waters.

The first trend has been reviewed by Craig (1984). In brief, both the present study and others have documented the absence or very low density of anadromous fishes in offshore marine waters although the overall sampling effort in this zone has been low. Anadromous fishes prefer warm water temperatures, the warmest of which occur in a brackish water band directly adjacent to shore. This estuarine band occurs along the entire Alaskan Beaufort Sea coastline (750 km) but is narrow (usually

2-10 km in width) except off the mouths of large rivers where plumes of brackish water may extend 20-25 km offshore.

The second trend in fish distribution is that fish are frequently most abundant along shoreline edges rather than in the open waters of the lagoon. This finding is similar to that obtained in Kaktovik Lagoon where shoreline gill nets caught 30 times more fish than in mid-lagoon sets on three dates when paired sets were made (Griffiths et al. 1977).

Many *fish* travel parallel to the shoreline along a surprisingly narrow corridor. It is a common observation that gill nets attached to the shoreline catch many fish while nets set only a short distance seaward of the shoreline catch few fish (e.g., McAllister 1962, Kendel et al. 1975). On some occasions the fish may even swim within a few meters of the shore. For example, Griffiths et al. (1975) noted that on one unusually calm day when schools of fish could be observed from a shoreline bluff, 10 or 12 observed schools of Arctic char and Arctic cisco were migrating in "shallow water (0.3 to 1.0 m) about 1-5 m from the shoreline. Furniss (1975:37) also noted that in Prudhoe Bay large numbers of Arctic char sometimes migrated "very close to the shore in extremely shallow water".

It would be erroneous, however, to leave the impression that fish are always concentrated along Beaufort Sea coastlines. We observed situations where this did not occur in Simpson Lagoon and other studies have also documented that there is less preference for shoreline habitats in the plumes of brackish water off the mouths of the "larger North Slope rivers (Griffiths and Gallaway 1982. Griffiths et al. 1983).

Another point to emphasize is that, although fish are concentrated along shorelines in Simpson Lagoon, the lagoon center probably accommodates as many fish because of its relatively large size. The following calculation illustrates this point. From Table 2, the average number of anadromous and marine fish caught in each meter of gill net was determined for each station. These stations represent particular types Of habitat (mainland edge, lagoon center, island edge), and the extent of each habitat can be estimated along a cross section of the lagoon from the mainland to Pingok Island. Using these sets of figures, the relative number of fish calculated for shoreline and lagoon center are:

Sta. No.	Habitat Type and Estimated Width Across Lagoon	No. Fish/in of gill net		Relative No. Fish in Habitat Type	
		anad.	marine	anad.	marine
1	mainland edge (100 m*)	0.78	0.08	78	8
2	lagoon center (4500 m)	0:03	0.01	135	45
3	island edge (100 m*)	0.28	0*04	28	4

● estimated on basis of Figure 5.

Although these calculations are rough, they show that a theoretical gill net set across the whole lagoon would catch 106 anadromous fish (78 + 28) in shoreline habitats and 135 anadromous fish in the lagoon center. It would appear, then, that the total number of anadromous fish in the lagoon center is similar to the total number of fish along the shoreline edges. In contrast, marine fish are more abundant in the lagoon center than edges (45 fish vs12 fish).

Why fish tend to concentrate along shorelines is not known. Itis not to avoid predators (densities of potential predators are very low--Craig and Haldorson 1981), nor is it to seek food (prey are even more abundant in deeper waters away from the shoreline--Griff iths and Dillinger 1981). We suspect that there are other behavioral and topographic aspects contributing to the observed shoreline abundance of fishes. First, anadromous fishes in the Beaufort Sea prefer warm water temperatures (Fechhelm et al. 1983, Neill et al. 1983, Griffiths and Gallaway 1982, Griffiths et al. 1983), and waters are warmest near shorelines, particularly the mainland shoreline; however, a behavioral response to temperature alone is not entirely satisfactory because waters in the lagoon center are slightly warmer than along the barrier island shorelines but the CPUE was not correspondingly higher in the lagoon water. Perhaps the shoreline concentration of fish is simply a thigmotactic response or even an artifact caused by the movements of fish through a preferred nearshore habitat which is very long and narrow, i.e., Simpson in particular and the coastal band of estuarine water in general. In addition, points of land that jut into Simpson Lagoon may act as 'diversion lines' for fish migrating east or west--a proportion of the fish crossing an embayment would encounter the landmark below its tip and follow its shoreline in order to get around the point, thereby resulting in larger concentrations of fish at that shoreline location.

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LGL
Alaska Research Associates, Inc.

Suite 201, 505 West Northern Lights Blvd.
Anchorage, Alaska 99503
(907) 276-3339

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2950 Fritz Cove Road
Juneau, AK 99801
25 January 1984

Dr. M.J. Hameedi, Acting Director
NOAA, OMPA, Alaska Offic e
P.O. Box 1808
Juneau, AK 99802

CITNo 4257

Dear Jawed:

Enclosed is a copy of my manuscript describing OCSEAP-sponsored research which I have prepared for publication as per P.O. No. NA83APA177. It is entitled "Fish composition and distribution in an Alaskan arctic lagoon", and I have submitted it to the journal Polar Biology.

Although the discovery of arctic oil has led to a number of fish studies, virtually all of this information can be found only in the gray literature of government and consultant reports, and thus is inaccessible to many researchers. The Simpson Lagoon study, upon which our manuscript is based, is one of the more comprehensive studies of the nearshore ecosystem in Alaskan arctic waters. This information should prove useful to a broad range of researchers concerned with biological investigations and industrial impact studies in the Beaufort Sea.

Sincerely,

Peter Craig

Peter Craig

cc. John Cole